Experiences with Using Solar Photovoltaics to Heat Domestic Water

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SCOPE

- ***Description and Operation of a PVWH System***
- ***Research and Demonstration Sites***
- ***Results From Single-Tank (Research) Sites***
- ***Comparison With Other Renewable Alternatives***
- ***Overall Experiences With the Technology***

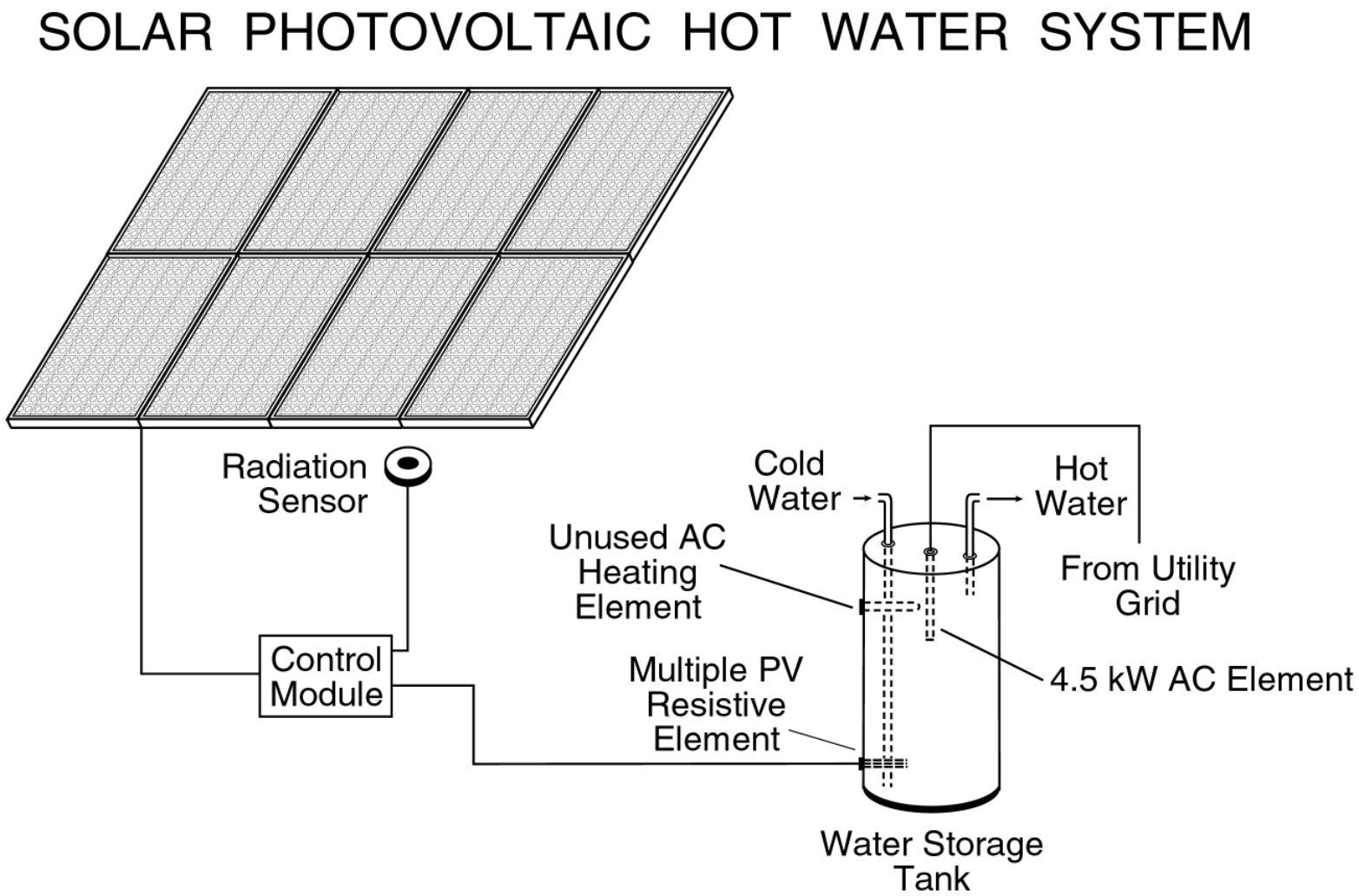
PV Water Heating System Rationale

- ***Off-grid Application for Using Photovoltaic Energy***
- ***Use DC Energy From PV To Directly Heat Domestic Water***
- ***Use Multiple In-Tank Resistive Elements to Operate Photovoltaic Array At or Near Its Maximum Power Point***
- ***Use Water As The Energy Storage Device / System Flywheel (Versus Batteries or the AC Grid)***

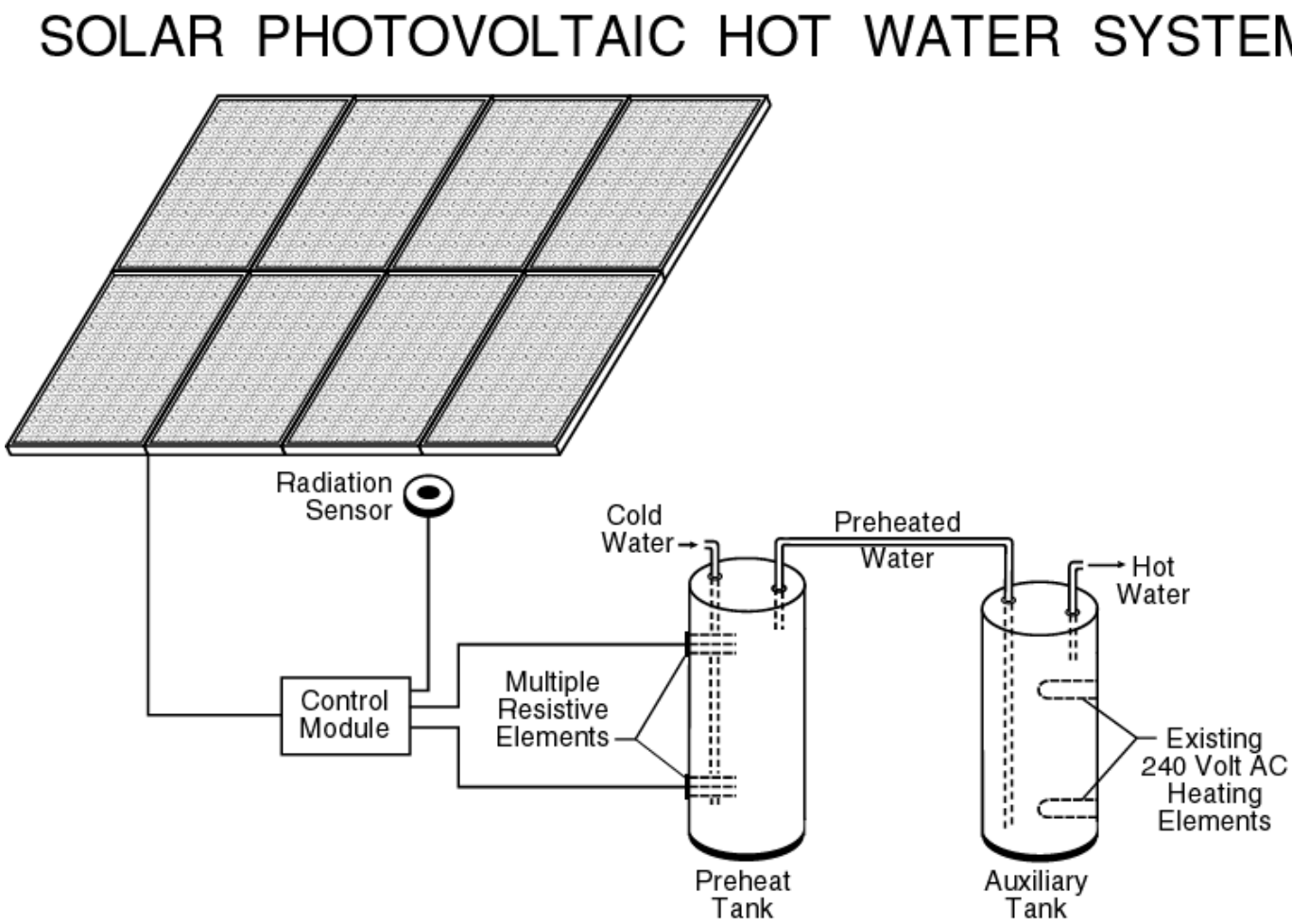
PV Water Heating System Components

- ***Typically 750 to 2500 Watt photovoltaic array***
  - ***Array areas: 6 to 20 m^2 (64 to 216 ft^2)***
- ***Unique Balance-of-System Components***
  - ***Control Module***
  - ***Solar Radiation Sensor***
  - ***PV Resistive Element Assemblies (1 or 2)***
  - ***Two-element electric water heater (1 or 2)***
- ***Balance-of-System Components Avoided***
  - ***DC-to-AC Inverter***
  - ***Storage Batteries***
  - ***Maximum Power Tracking Power Conditioning Electronics***

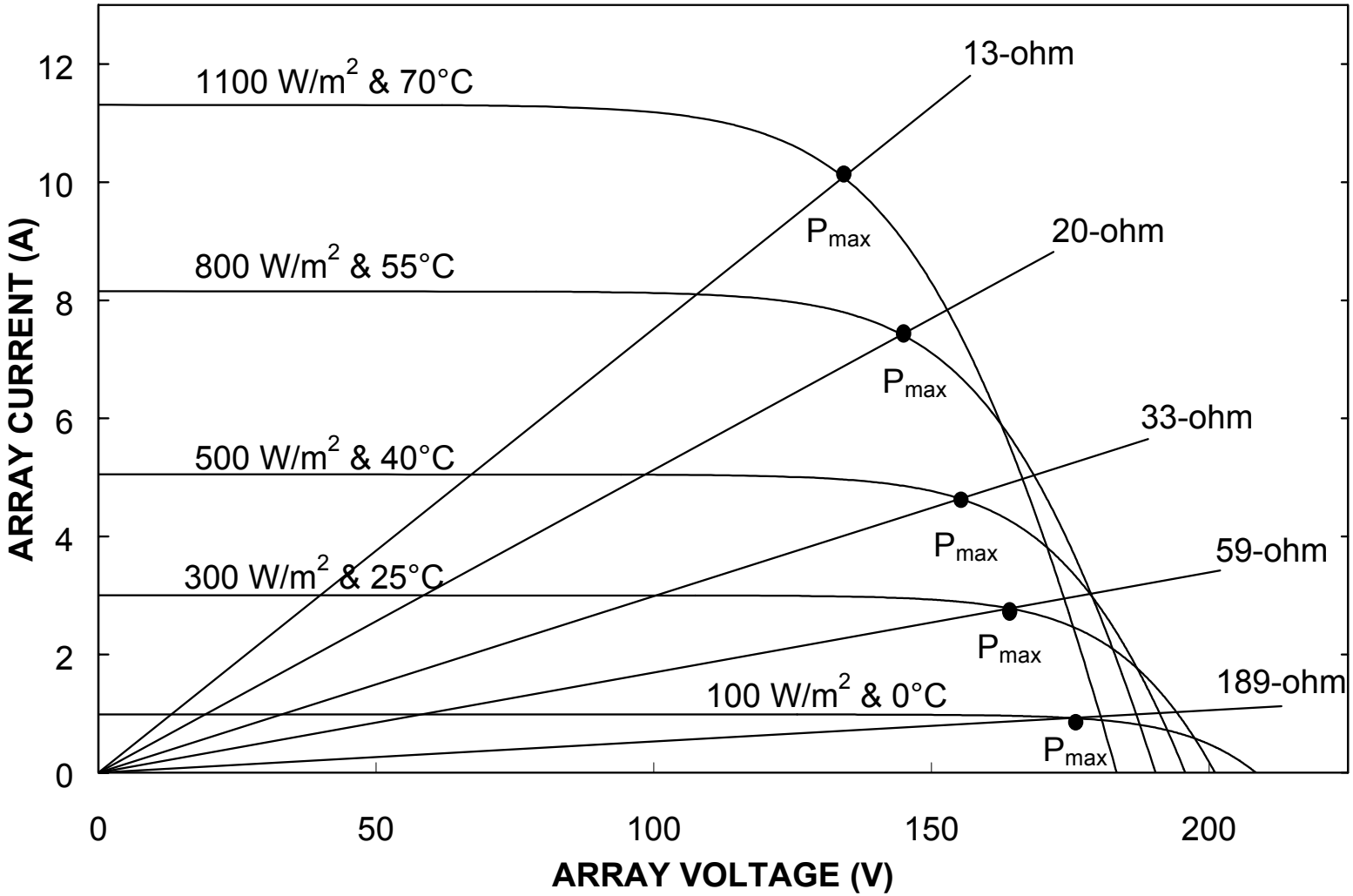
Single-tank PVWH Schematic



Two-tank PVWH Schematic



PV Array I-V Curves with Load Lines



Research and Demonstration Sites

- ***NIST (Research)***
  - ***Two-tank systems***
  - ***Single-tank system***
- ***FSEC (Research)***
  - ***Two-tank system***
  - ***Single-tank system***
- ***Great Smoky Mountain National Park (Demonstration)***
  - ***Two-tank system***
- ***Kadena Air Force Base, Okinawa, Japan (Demonstration)***
  - ***Two installations***
  - ***Both two-tank systems***

Kadena Air Force Base, Okinawa, Japan

Installed:
November 1997

- **Two Identical PVWH System**
- **Two-Tank PVWH Systems**

Sugarlands Visitor Center at the Great Smoky Mountains National Park

- ✡ **Two-tank PVWH System**
- ✡ **Largest PV Array: 2120 W_{peak}**

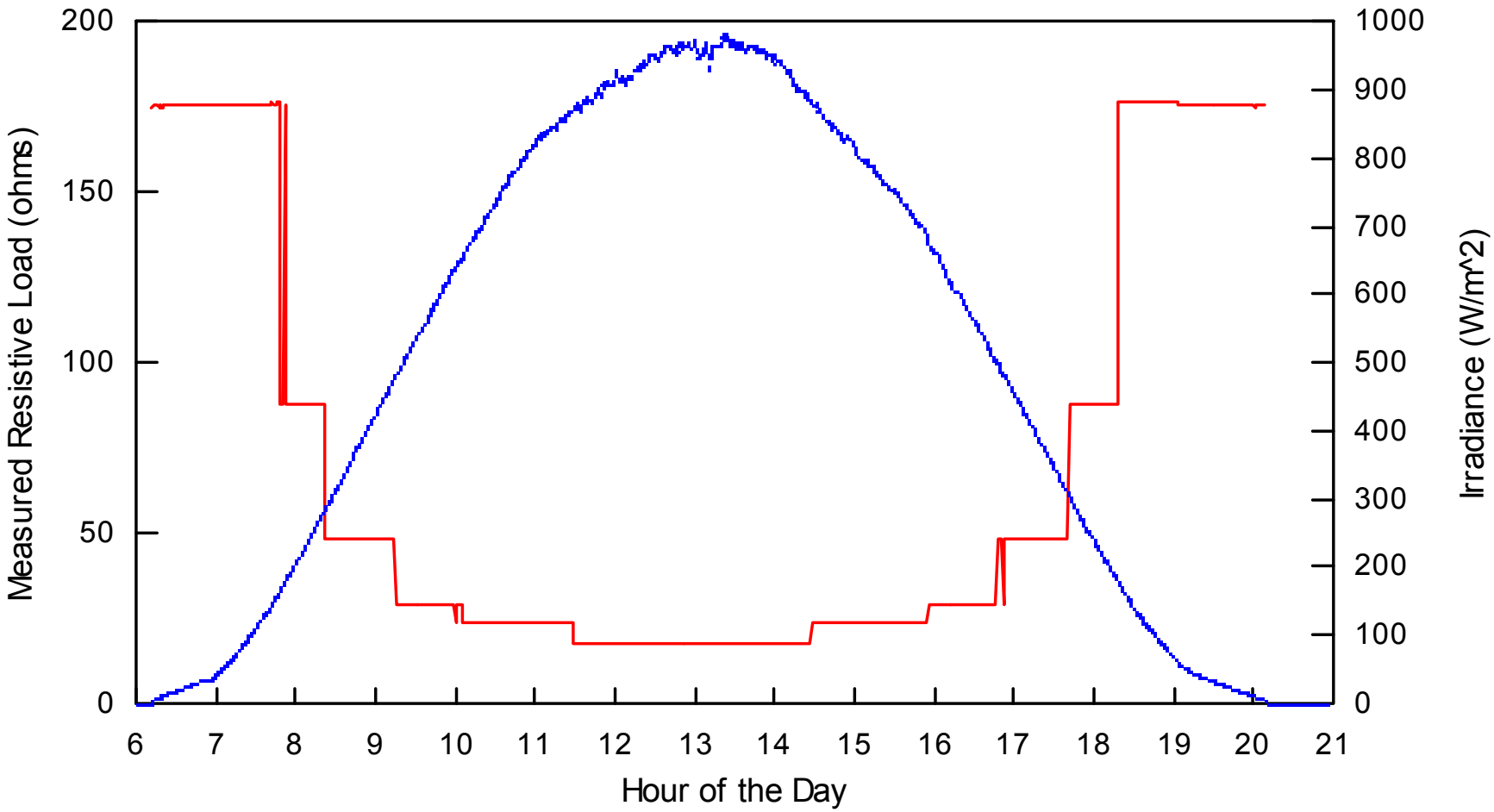
Installed: September 1996

Research Site: Florida Solar Energy Center

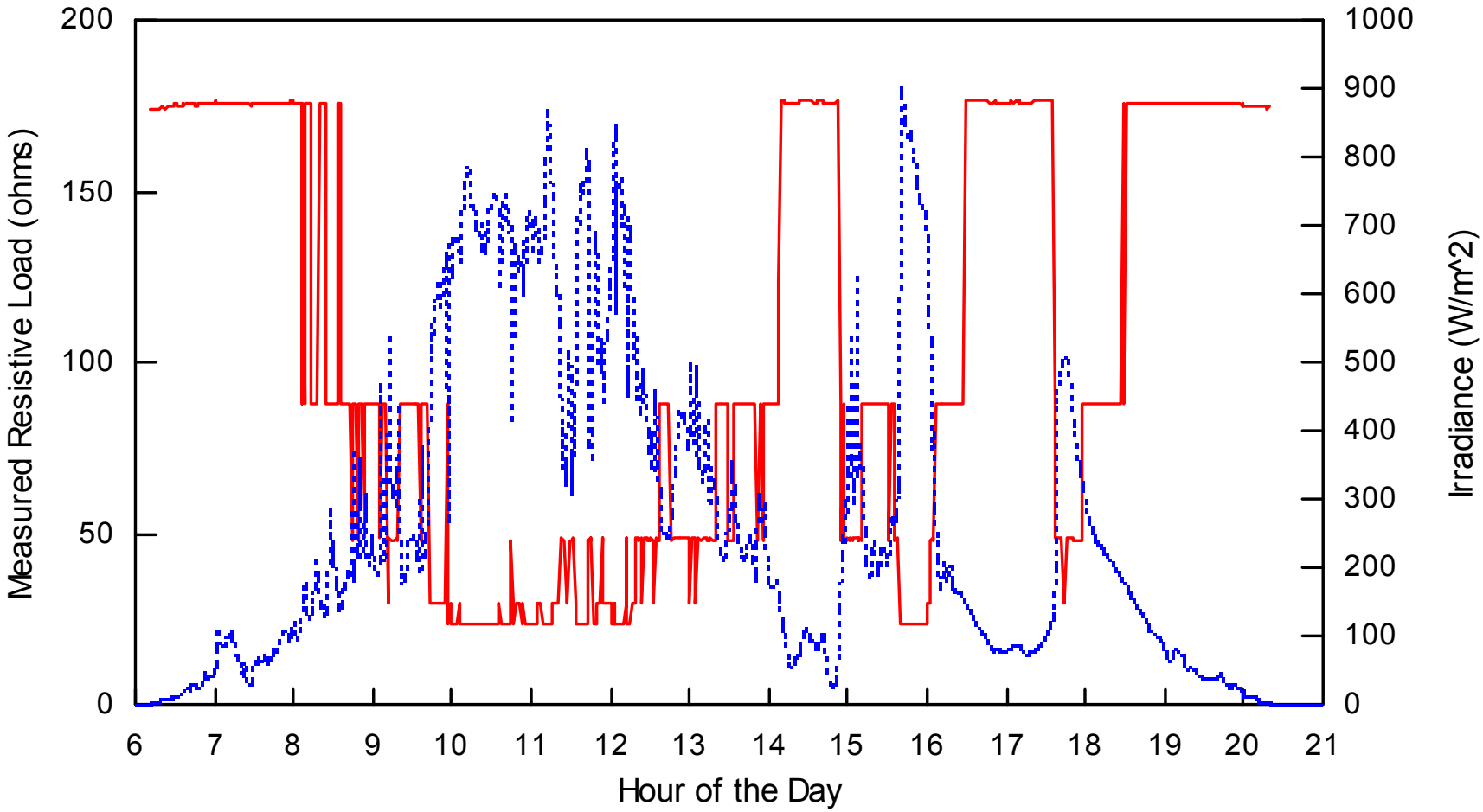
- ✡ **Two-tank System**
- ✡ **PV Array: 1431 W_{peak}**

- ✡ **Single-tank System**
- ✡ **PV Array: 1060 W_{peak}**

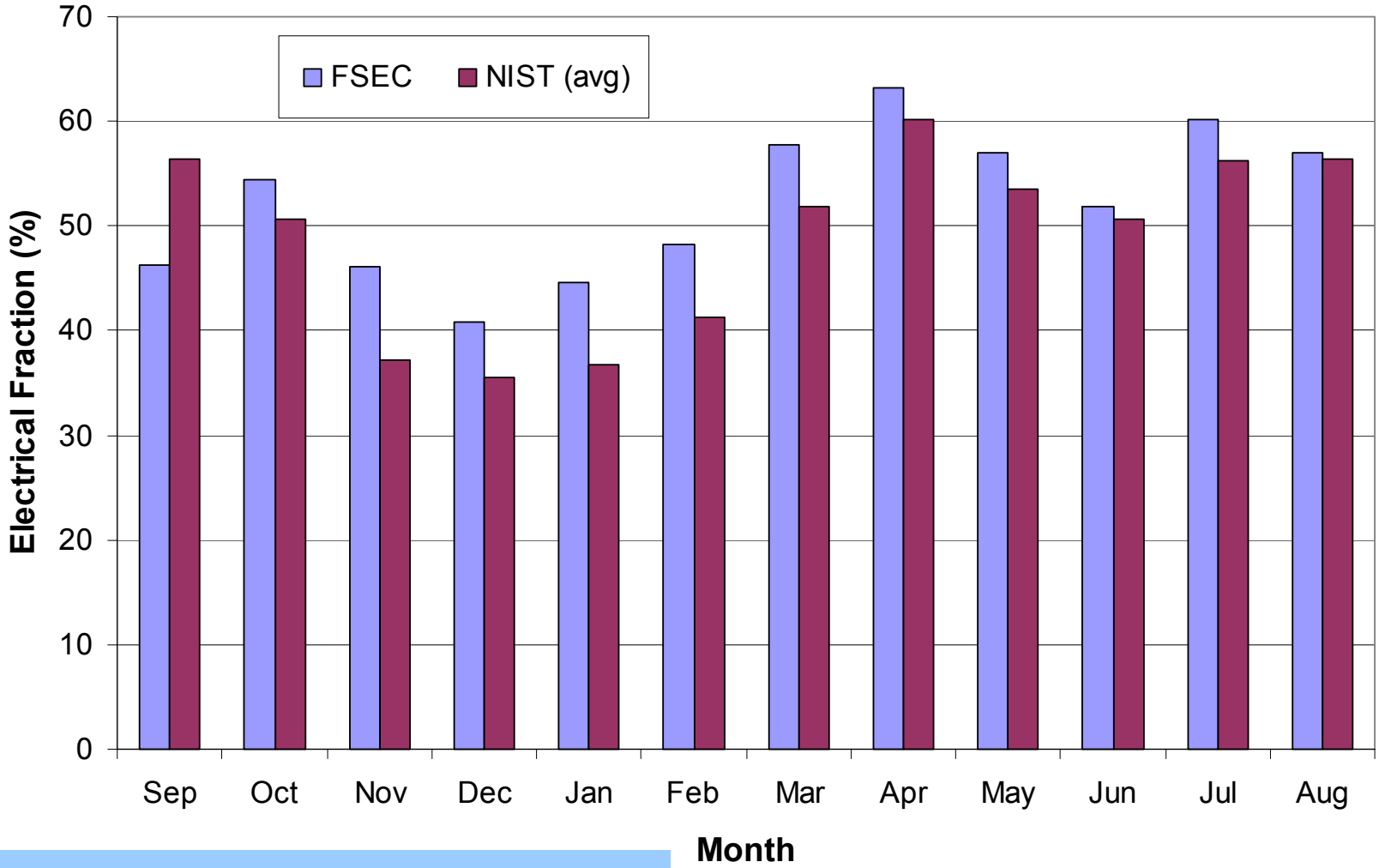
Resistive Load Variation: Clear Day



Resistive Load Variation: Cloudy Day



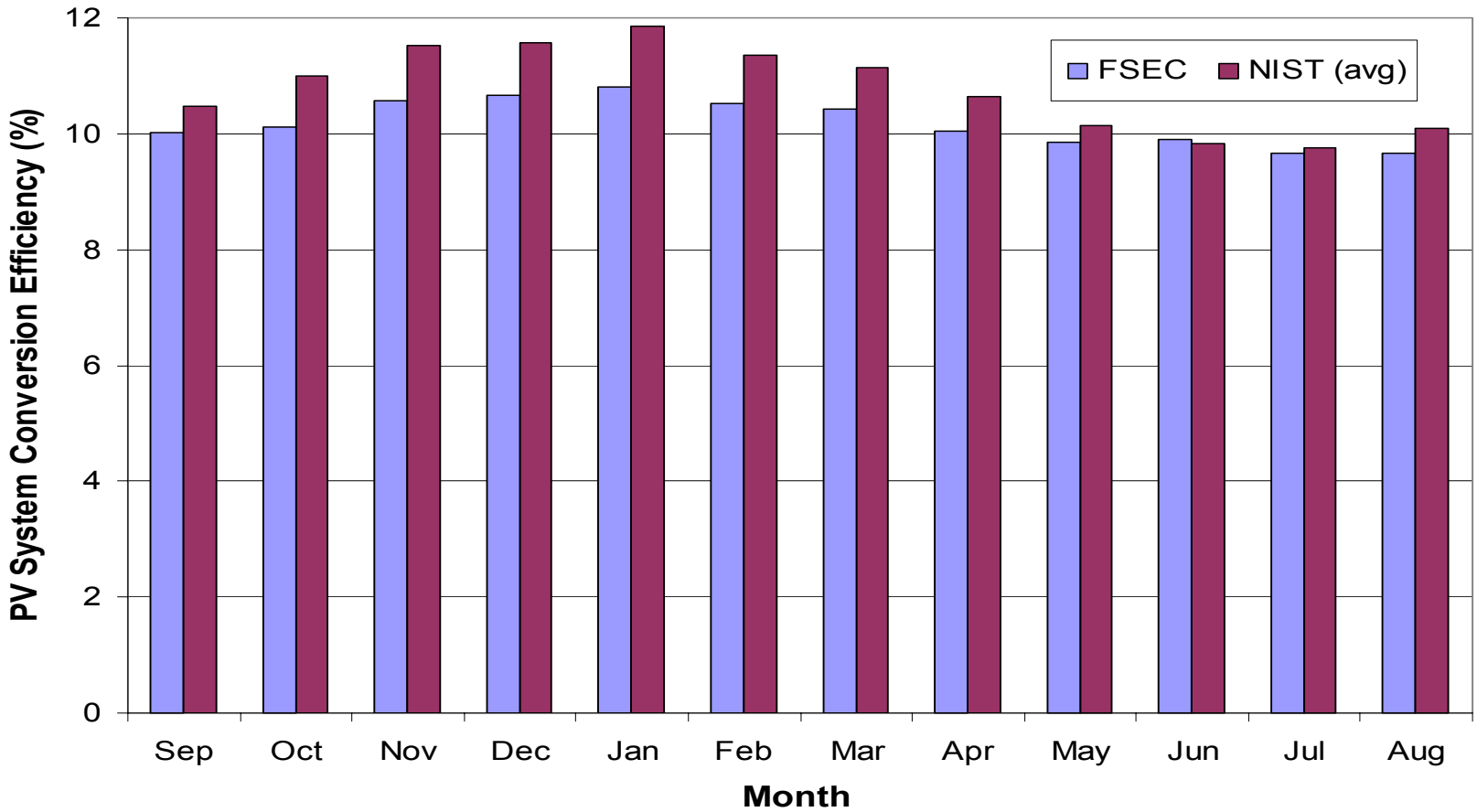
Single-Tank Electrical Fractions



12-month FSEC Electrical Fraction = 51.8%

24-month NIST Electrical Fraction = 49.0%

Single-Tank PV Conversion Efficiencies



12-month FSEC PV System Efficiency = 10.2%

24-month NIST PV System Efficiency = 10.6%

PVWH Versus PV Grid-Connected

- **Advantages of PV Grid Connected**
  - **Flexibility for multiple end uses**
  - **Potential for higher solar utilization**

- **Disadvantages of PV Grid Connected (although improving)**
  - **Higher balance-of-system costs**
    - **\$0.75 to 1.70 $W_{peak\ AC}$ for inverter (1 to 2.5 kW)**
    - **\$400 to \$450 for the PVWH controller, radiation sensor, and 2 PV heating element assemblies**
  - **Comparatively lower reliability; higher maintenance costs**
  - **Slightly lower conversion efficiencies**
  - **Greater burden: permitting, interconnecting,,& inspection**

PVWH Versus PV Grid-Connected: A Favorable PVWH Scenario

- **PV Array Size: 750 to 2500 Watts Peak**
- **Moderate to High Hot Water Consumption**
- **Hot Water Consumption is Regular Throughout the Year**
- **End User Otherwise Heats Water Using an Electric Resistance Water Heater (As Do 45% of the Homes in the US)**
  - ***-Avoid the cost, complexity, and loss of efficiency of converting DC array power into AC grid power and then using it to resistively heat domestic water***

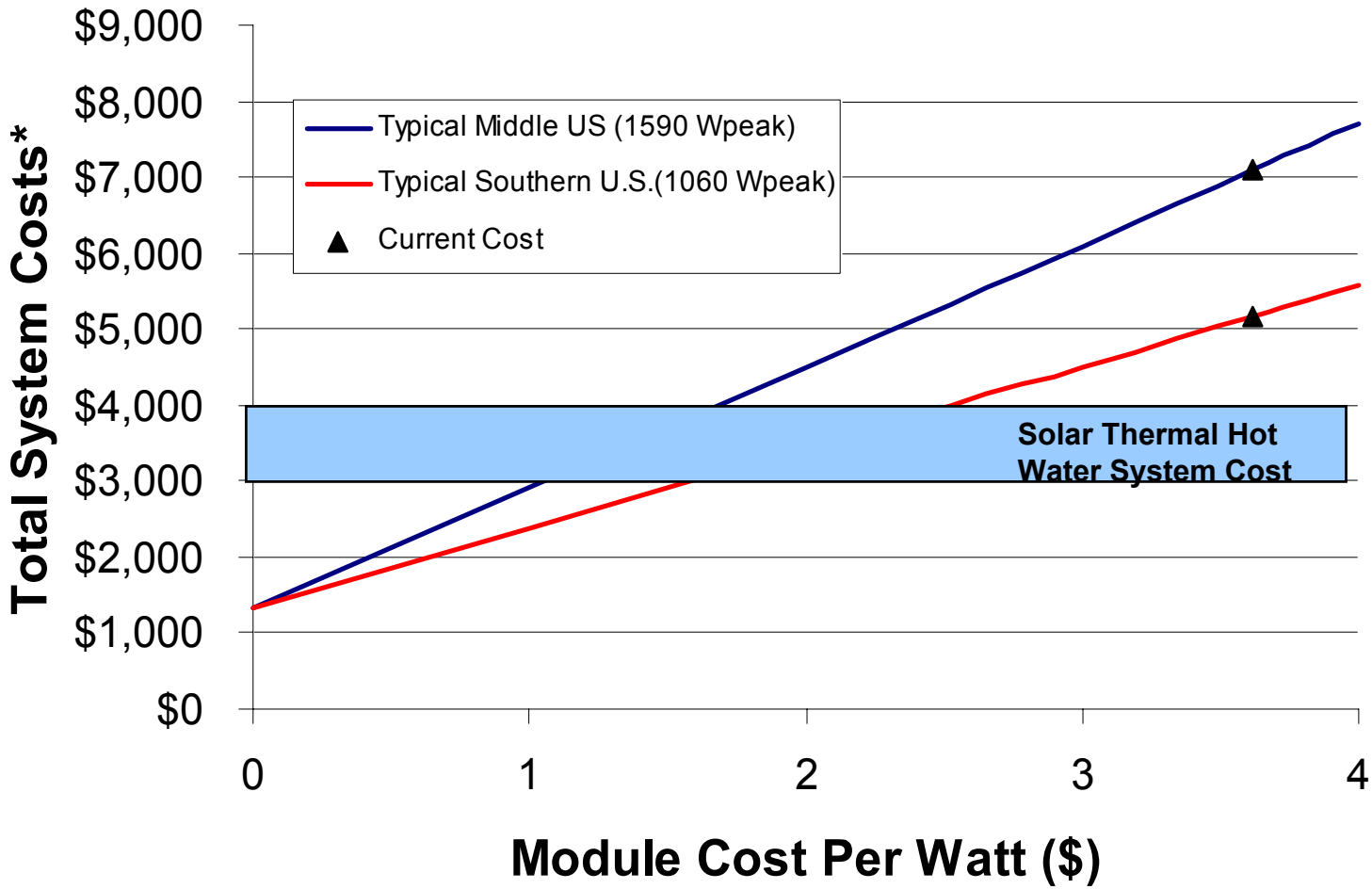
PVWH Versus Solar Thermal Water Heating

- **Advantages of Solar Thermal Water Heating**
  - **Lower initial cost (but gap is narrowing)**
  - **Higher conversion efficiency/smaller solar collector area**

- **Disadvantages of Solar Thermal Water Heating**
  - **Freeze protection contingencies for many locations**
  - **Lower reliability/life expectancy; higher maintenance costs**
  - **Pipes and fluids versus wiring and DC current flow**
  - **Can be aesthetically displeasing**
  - **Comparatively less promise for efficiency increases and manufacturing cost decreases**

- ***Key Question: Can the PV Industry Reduce the Cost of PV to the $1.75/$W_p$ Range?***

Hot Water System Initial Cost

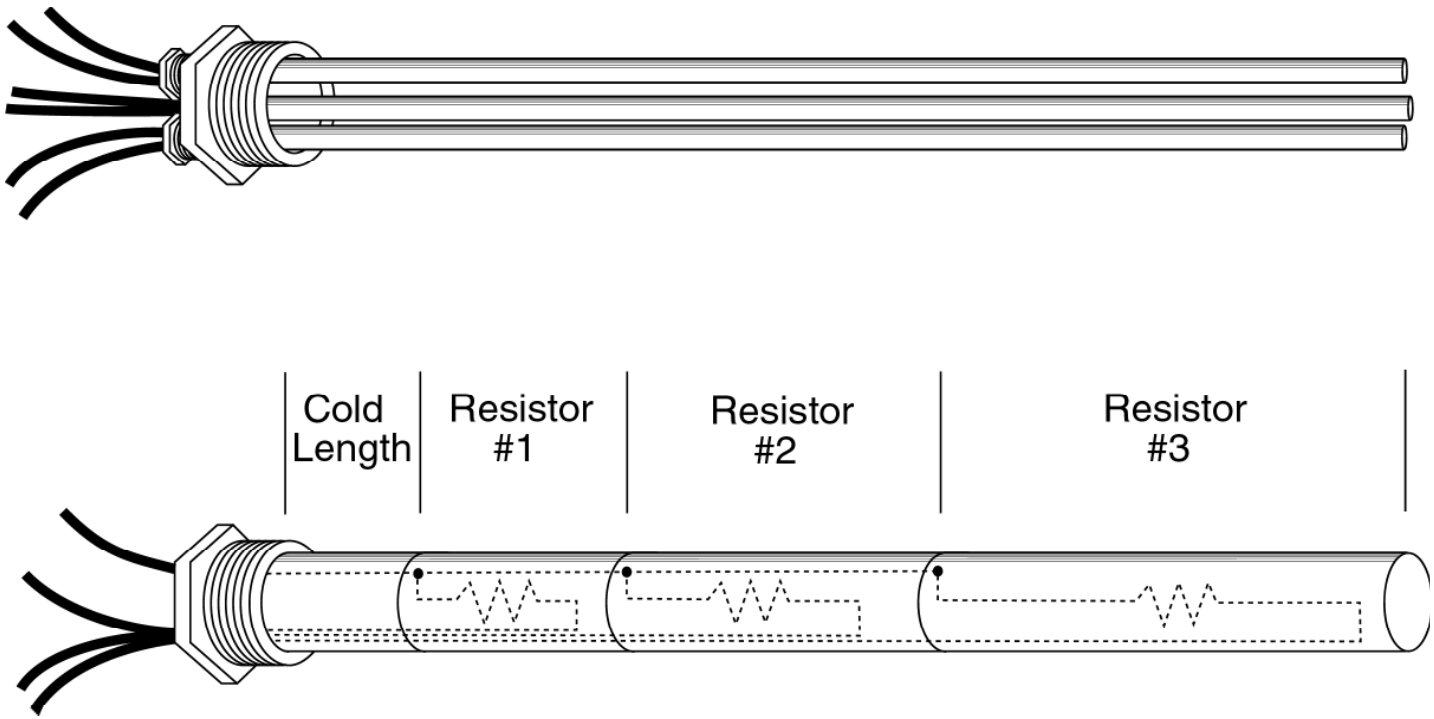


*Includes installation and balance of system costs

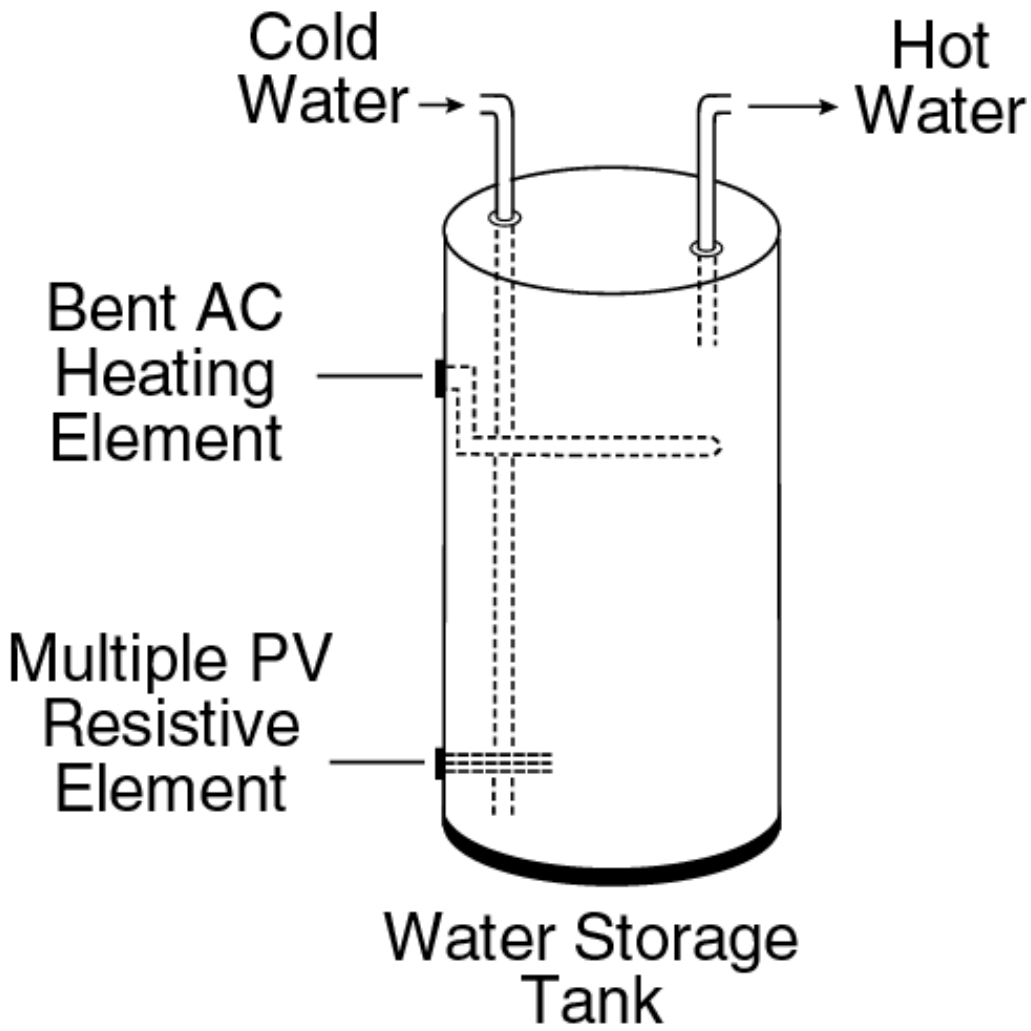
Overall Experiences With the Technology

- *17 years of operation among the 7 installations*
  - *Robust performance for prototype systems*
  - *4 cases of reduced PV energy generation (no complete failures)*
    - *Shifted resistance element (51 ohms to 78 ohms)*
    - *Faulty PV module (1 out of 145)*
    - *Loose fuse for one string of modules*
    - *Failed electrical connection at module junction box*
- *Applicable to two-tank and single-tank configurations*
- *Potential market if the $\$/W_{peak}$ drops to the \$1.50-\$2.00 range*

PV Multiple Heating Element Assemblies



Alternative Single-tank Design: Bent AC Element



Summary Results

PVWH System	PV Array Rated Output (W)	Annual PV Energy Production (kWh)	Ratio of Annual Energy Production to Array Rated Output (kWh/W_{peak})	Electrical Fraction (%)	PV System Conversion Efficiency (%)	Average Daily Solar Irradiance (kJ/m^2)
NIST Two-tank	1590	2243.4	1.41	44.6	11.0	15750
FSEC Two-tank	1431	2176.8	1.52	67.0	10.0	18570
Kadena I	1272	1487.4	1.17	25.8		
Kadena II	1272	1522.3	1.20	28.0		
NIST Single-Tank	1590	2190.3	1.38	49.0	10.6	15870
FSEC Single-Tank	1060	1612.6	1.52	51.8	10.2	18270